Naval Platform Control Systems 2015 and Beyond

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This re-print of the original INNC 1997 technical paper has been produced by the principal author, Joseph Famme, August 2003. Mr. Famme is now President of ITE Inc., Arlington, Virginia www.ITEinc.US

Abstract

The challenges for ship designers are time and change. Time: the ship design and construction can take ten years. The resulting ship will be expected to serve its navy for thirty to forty years! Change: The thirty to forty year time span of a ship's life will see major changes in the world political environment, technology and resulting threat. How well can a ship and its control systems be designed in the face of these challenges? The high weapon lethality and short response time to react to modern threats, combined with projected manpower reduction in naval ships, will lead to increasing levels of automation and systems integration. This level of integration is predicted to give way to a merging of ship control and combat systems control networks into an environment of ubiquitous computing, supporting what has been described as an "autonomic" ship operational and threat response system. Some ships may be operated by remote control from a combined operations / ship control center during portions of their combat mission. This merging of functions and architecture may extend to inter-ship engagements (cooperative engagement) and extend to integrate ship systems from many allied navies. This paper will postulate the design of future platform control and monitoring systems to support future naval warfare requirements in the time period 2015 and beyond, and discuss the impact of the future requirements on platform control systems hardware, software and personnel.

1 Introduction

It is a privilege to have been given the opportunity to present this paper. Since it is our profession to design, build and operate naval ships in the defense of free world interests, we must have a clear idea of the environment in which our creation will have to serve. Understanding the environment factors of demographics and economics, technology advances and the resulting threat will better enable us to better design and build a ships in the next several years that will serve our navies well into the mid-21st Century, supporting the next two generations of the citizens of our countries.

Clearly, time is the critical factor in our considerations. It takes about ten years to conceive, design and build a ship, and that ship will be in service for 30 to 40 years. It is not an abstract problem. The crews of these ships will be two generations of our descendants. They are counting on us to anticipate their requirements. How do we design for a future that encompass major potential changes in political structures, demographic and economic pressures, threats and technologies that our descendants will face 30 to 40 years from now. How much effort shall we put into divining the future? Is it worth it? We say, "Yes," and we are that sure that our descendants will be grateful that we had done our best.

Let's try to put our challenge in perspective by looking at some of the major factors that will shape our future and what might be able to project.

Section 2 of this paper will discuss selected world demographics and major economic factors that will affect the motivations for future warfare. This environment will provide the manpower and financial resources to build our ships. Section 3 of the paper will discuss the technology resources that are projected to be available for war fighting purposes, both for ourselves and for potential enemies of freedom. Section 4 of the paper will discuss the threat that our free world ship will face. The threat definition will define the requirements for the design of the new ship tied to anticipate naval missions. Section 5 of the paper will postulate the ship control systems that we might design in the 1990's that will serve our ship and its crew to 2015 and beyond. This section will also discuss the human factors impact of the future control systems.

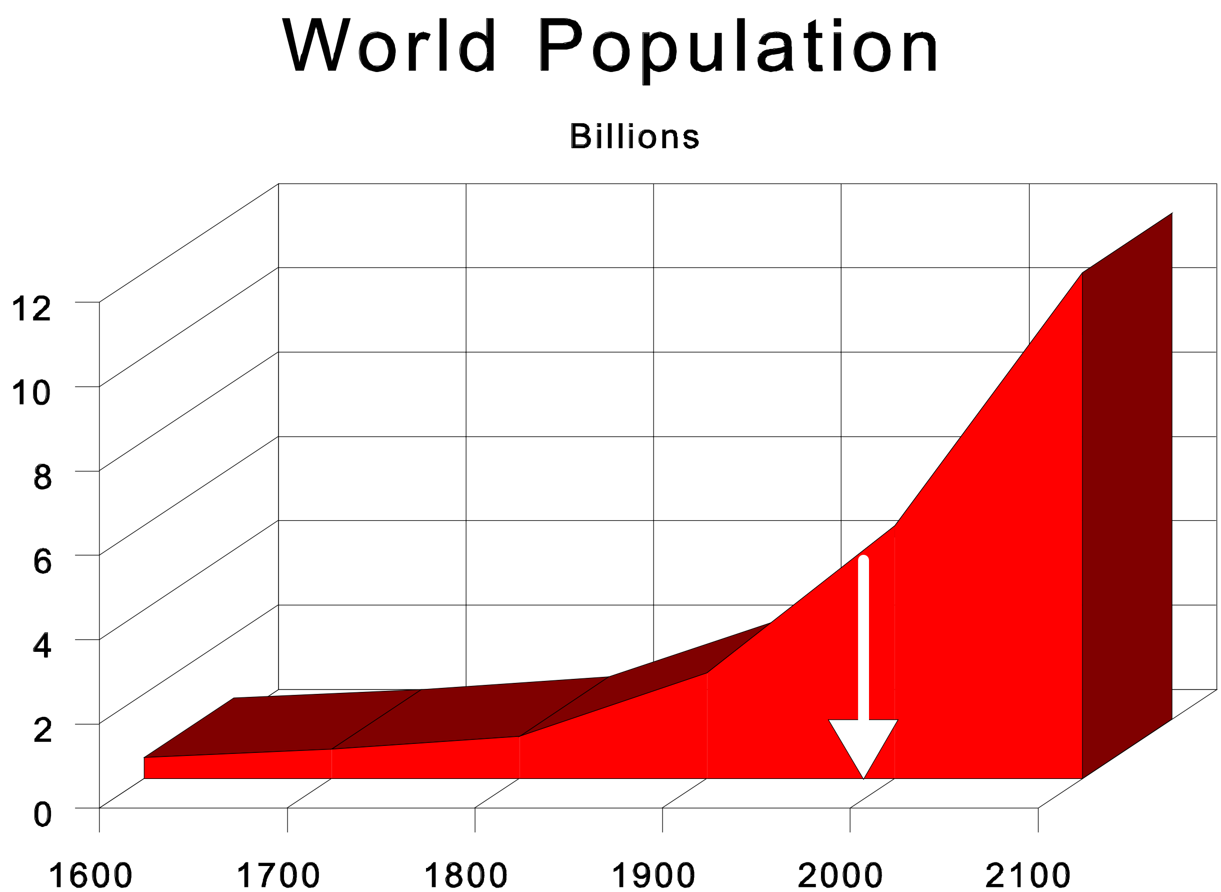
2 Environmental Factors

2.1 Demographic Factors

Most futurists believe that growth in world population will be the largest factor in determining our future depending on how we adapt our behavior to cope with the challenges of demographic pressures on food supplies, world economics and political instabilities.

Demographic studies show world population approaching the upper sustainable limit of about 12 Billion by 2100[i]. Figure 1 shows the current world population trends based on world population in at the turn of the centuries 1600 through 2100. By 2100 there are projected to be twice as many people on earth as today, 12 times the population in the year 1800!

The implications of population growth are enormous. Will population growth go beyond the sustainable limit? How will events leading to this magnitude of growth affect our



lives, economies and future conflicts?

Sub-elements within the demographic factors include the anticipated growth in the older and younger segments of society. Improved health care will continue to extend the life span of elder people adding to their numbers and related demands for housing and medical funding in competition with defense spending. At the same time, the pool of young people will also grow, but primarily in undeveloped countries. The younger people normally make up the bulk of defense forces personnel. The developed countries will probably continue to experience a shortage of skilled youth because of their small numbers and the increasing preference of youth to go into the private sector business where the pay is considerably more attractive than the defense forces. At the same time, the population of youth in the undeveloped countries likely will grow in an environment of poverty and lack of training and education. These youth

are a potential source of unrest as they mature if they come under the influence of leaders that have a desire to instigate instability. In parallel, some forecasts of demographic trends also projects that societal value changes in the 21st century will see women leaving the workforce and fewer available for defense forces[ii].

The increasing populations in the undeveloped world are projected to continue to exert immigration pressures into the developed countries which will further add to the social costs in these countries.

In parallel with these demographic trends, we are also seeing social pressure in the free world societies to fight bloodless battles, if they should be fought at all. The Allied experience in the Gulf War gave the impression that hundreds of thousands of soldiers can fight a major battle with the loss of just over a hundred allied soldiers (with most of those lost behind friendly lines). The US experience in Somalia showed that the public had no tolerance for the loss of 17 soldiers during a rescue operation. The US humanitarian mission was terminated before achieving its objectives. The lesson learned seems to be that every effort must be made to reduce human risk in combat, what we call human risk mitigation (HRM). The only way to prevent the loss of human life in combat is to not put humans into a combat situation in the first place. The next option in HRM is achieved by replacing humans with automation and remote control systems. These design factors will be discussed in Section 5 of the paper.

2.2 Economic Factors

While economics are not the subject of this paper, we must appreciate the cause-effect relationships of population growth and global competitive economics on political instability toward the outbreak of wars (crisis). In their book, *War and Anti-War, Survival in the 21st Century*[iii], the Toffler's research supports strongly the concept that economic competition pulls the trigger.

2.3 Globalization

Depending on outlook, the globalization of business, ideas, finances and populations that we have seen can be a positive or negative factor in stabilizing the world political situation. For many, however, globalization is viewed as threat to the status quo, an invasion by other means[iv].

If the population and competitive economic trends continue, there will be no shortage of conflict. It is up to us then, in the service of our citizens, to understand the nature of the potential threats, and design and construct naval vessels that will keep the peace in future conflicts.

All of these environmental factors will impact how we design of our new ships.

3 Technology Factors

Most of us try to live in the present. At least that is what most advisors tell us to do. This allows us to appreciate each day and hopefully, each other. It also seems to serve the useful function of allowing us to believe, most of the time, that we are indeed fortunate to be alive in "our time" and that we have "gone about as far as we can go", to borrow from the musical play *Oklahoma.* But then, at occasions like this, we get paid to look into the future.

So, let us step from the present and into the future as far as we can, even if it is a stretch. Only if we stretch to reach a consensus of the future are we likely to cause sufficient mental challenge to open and sustain the necessary debate. This might lead to better navies.

This section will explore from several perspectives the technologies that will be at our disposal for the design and operation of our naval ships over the next forty years. These technologies and their supporting architecture will then be applied to our future ship systems in Section 5. We will look at the term information age, and then the underlying technological trends in computational and communications systems.

3.1 The Information Age

We can agree, most likely, with the premise advanced by the Tofflers[v] that we have moved from the age of brute force-based warfare to the age of knowledge-based warfare. The enabling technology has been computational power - the computer. In war fighting terms this has meant a change from the brute force carpet bombing used up through the 1970s, to the use of precision-guided bombing and cruise missiles used strategically and tactically in the Gulf War. The Gulf War also brought us the first major systematic campaign in knowledge warfare where Allied forces destroyed the Iraq's ability to detect and classify targets and communicate with their troops in real time.

John Peterson is a consultant to the US Department of Defense and regularly meets with US defense and commerce officials to help them try to decide how far to stretch their view of the future as they design the new defense systems for the USA. It's the information age which supports knowledge warfare as we understand it. Mr. Peterson, in his book, *Toward 2015*, states that with the advent of the micro-computer technologies that the total base of world information is doubling every 18 months[vi]. This tracks with what we have seen in the market place with micro-processors where the processing / memory requirements have doubled every 18 months in constant dollars. How long this dramatic growth will continue is yet to be determined. We have to design our ships with these factors in mind.

John Peterson offers an additional insight. The stages of technology development, or ages, as we have defined them, have become increasingly shorter. The

town/city/agriculture-based age lasted about 5000 years to be replaced by the emergence of an understanding of our physical reality starting with Copernicus (1473-1543) leading to the industrial age in the 18th century, a total period of about 500 years. And now we are in the information age, and Mr. Peterson's research suggest that the information age will last only about 50 years to be replaced by the age of quantum mechanics. Starting with Max Planck and Albert Einstein, and with the contribution of others, we are beginning to see another dimension of thinking about existence and how we interact. The new physics says that there is nothing solid in matter - no solid electrons, protons or sub-atomic particles.[vii] New physics suggest that everything is connected to everything else by packets - chunks - of energy. The ultimate extension of the new physics is the one thing decides what is real is human consciousness. This new physics is built on the theories of quantum mechanics, which, among other things, suggests that you, the observer control the reality in which you live. The ultimate situation of virtual reality!

The hoped for leverage of quantum mechanics is that the power of these tools and the supporting technologies will help all of us in the future to deal with what more and more observes see as a trend toward chaos in many segments of our populations. Further discussion of quantum mechanics will be left to a future paper.

That the concepts of the information age and the theories of chaos are relevant and are being incorporated into current planning can be seen in the future vision of the Commandant of the US Marine Corps, General Charles Krulac. In a speech to the Surface Warfare Association in June 1996[viii], the Commandant described the evolution of warfare that more or less matched the technology of the ages: maneuver warfare (based on brute force) for force on force engagements, precision strike (based on computational power) to fight crisis situations using guided munitions, and now information warfare (based knowledge) to deal with chaos. What is chaos? Chaos is what we in the free / civilized world are more and more facing in warfare. Chaos is manifested by terrorist acts and improved forms of guerrilla warfare. It could result in the unprovoked launch of theater ballistic missiles, the use of suitcase bombs to release chemical, biological or nuclear weapons, or the use of commercial ships to place time delayed or remote controlled mines. Enemies of the free world have found it impossible to fight force on force with the modern forces and their tightly integrated command, control and intelligence capabilities. Our enemies will try to find ways to fight with deception and target masking. They will also attempt to break into our computer systems to gain information or destroy our computers through the use of viruses.

Factors like these are reasons futurists have been made part of the defense planning cycle. The pace of change is accelerating. It is sobering to look at the societal and technology changes that we will see over the life of the ships we are now designing.

Figure 2 provides a very simple graphic of the growth of computing power technology / knowledge from 1940 to 2050 in decades overlaid with the design and operational time line of our new ship. This graphic doubles the computational power conservatively, only every decade, rather than the every 18 months as some experts suggest. In fact, according to ARPA data, the power of computers by unit cost is increasing at a rate of 4000 times per decade[ix]. A

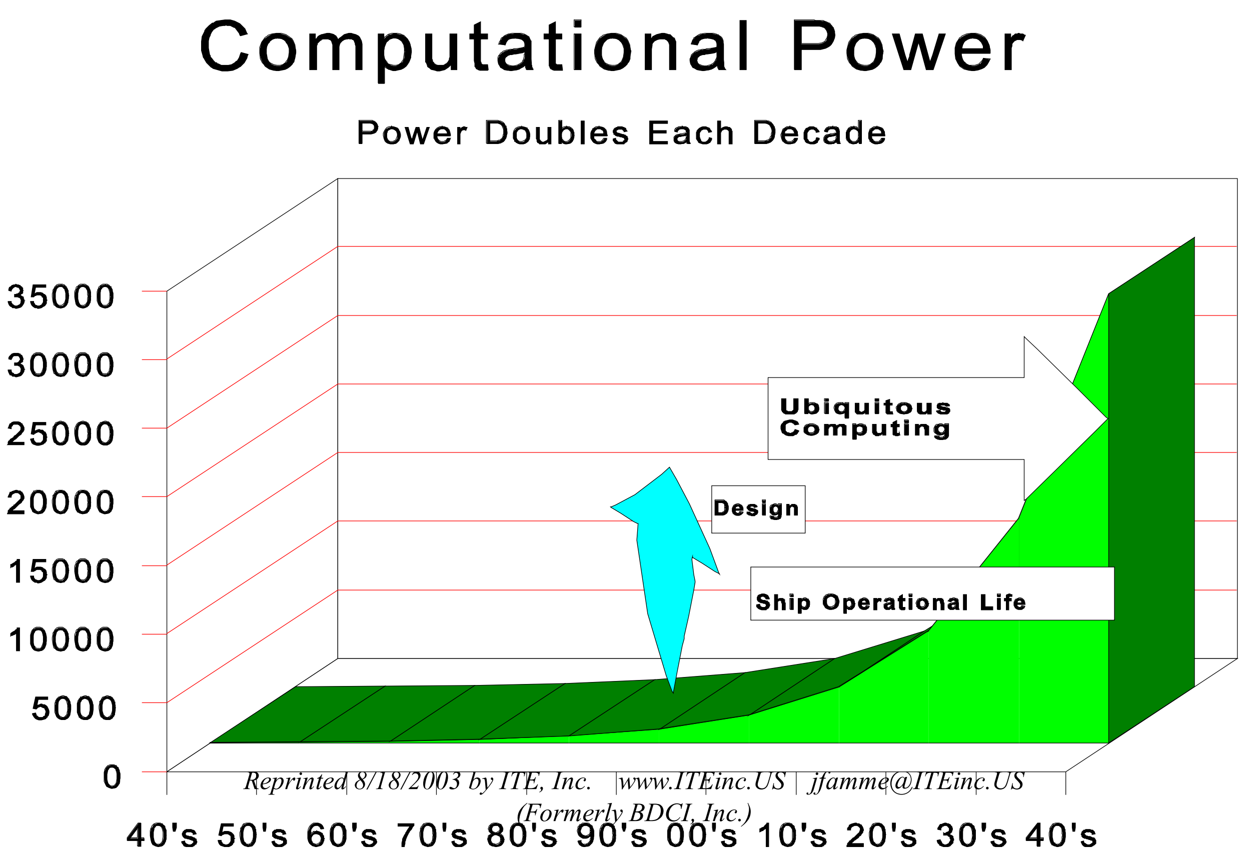
projected holographic memory device will store more than 10 gigabytes of data in a crystal smaller than a cube of sugar.

The point is, even with a conservative estimate of computational power based productivity improvements for the average sailor as shown in Figure 2, our new ship in over its life will be in a world of knowledge and technical capabilities that we can imagine only faintly.

3.2 Bandwidth

Another way to view the technology trends and opportunities is through the eyes of noted author and economist, George Gilder. In a presentation to the Aspen Institute in 1996[x], Mr. Gilder made the following points that may drive our designs in the future. George Gilder stated that the only scarcities in life are time and our current life span. The limitations on computational and communications power are virtually unlimited if we engineer our systems properly. Given the speed of light as the current upper limit of electron speed, and the nanosecond as the iteration time factor, future computers will have to be built so that the longest wire path is 9" or less, leading to smaller computers. Once computers are at maximum speed, the next design factor is communications speed between computers.

George Gilder makes the point that our economic history has been driven by technology. The industrial revolution was driven by dropping unit cost of a horsepower of energy. The computational based information age has been driven by the decreasing unit cost of the transistor. He states that the next major driver of our economies will be bandwidth, and



that we will develop virtually unlimited bandwidth in both RF and light (fiber optic) mediums as unit costs drop. The impact of unlimited bandwidth will be to support seamless distributed computer processing and inter-personal / inter-organizational communications (ubiquitous computing). An example of the difference is seen between TV and the Internet. TV is a centrally processed, broadcast medium at very low bandwidth and low inter-activity. The Internet reverses the paradigm giving full power to the users to choose the means of communicating / collecting information from anywhere to anywhere, at anytime. This is causing our knowledge base to explode, and so will the growth of network computers. It is projected that bandwidth available to communicate will increase to the range of 300 Terra-hertz.

Gilder sites Meads Law that N^2 transistors on a piece of silica results in N^2 performance of a computer. He also states N^2 computers on the network have the same effect. In this context, Mr. Gilder states that network power in 1995 passed through N^{32} since WWII. He believes we have not seen anything yet. In 1995, external E-mail out numbered post mail and PC sales outnumber TV sales by 25%. The challenge now is to stop wasting time and to continue bandwidth development, and he predicts that we will bring information to the user when needed, never go get it. The projection is that by the turn of the century that every individual that wants one will be able to have the equivalent of a super computer in his shirt pocket ... a wearable computer that can communicate.

When computer processing power and bandwidth to communicate are leveraged over the operational life of our new ship it will enter the era of ubiquitous computing. Computer processing will exist seemingly everywhere, within all equipment, systems, and worn as part of the every military "uniform". We are in a situation designing ships similar to the beginning of the age of steam in the 1700s, before automobiles, airplanes and computers were anything but the wildest concept by people who tended get locked up for the heretical ideas. We would have had little idea then of the impact of the new technologies. The rate of change (advancement of new ideas) was slower during the 1700s than it is now. It took 150 years to develop a self-propelled automobile after the discovery of steam. It took about 60 years to go from the first airplane to the moon. Our knowledge base is accelerating. We believe that we are expected now to try to forecast the advent of new technologies and setup our system architectures in order to be prepared to adapt to changes as they will occur. This is the object of this paper.

3.3 Hundred Knot Ships

Not only is the micro-world accelerating, so is the world of ships. Japan is testing magneto hydrodynamic (MHD) propulsion. If new ceramic or other superconductor materials can be found, ship speeds to 40 - 50 knots are projected[xi]. Even without MHD, however, there is a consortium of U.S. and European business interests putting plans together to produce 100 knot cargo ships. The economic basis for 100 knot speed is the just in time manufacturing of autos. Fast ships will reduce inventory staging costs and thus pay for themselves. Meanwhile,

the current market for fast ferries is demanding vessels that will cruise between 35 and 45 knots. The military implications of this development could be significant for programs like the USN arsenal ship.

3.4 Sensors

New technologies in manufacturing and power generation will open whole new opportunities in sensor systems. For example, molecular nanotechnology reverses the manufacturing process from top down to bottom up. New objects will be manufactured stating with a single atom[xii]. This technology will reduce the cost while providing custom design for strength, thermal tolerance, etc. Solar cells will be able to be made that are tough enough to be used for a road surface.

Condensed charge technology produces small, tightly bound, dense clusters of electronic charge (balls of lightning) of enormous power relative to their size[xiii]. The resulting "sparks", when controlled, can be used on command for such purposes as:

- **60 to 90 GHz radars the size of credit cards**
- **Disposable X-ray devices**
- **90 GHz communications frequencies**
- **Very high resolution flat panel displays**

Combine artificial intelligence, improved pattern recognition power, and nanotechnology with condensed charge technology and perhaps whole new families of sensors and actuators may emerge. Radar / sonar / video mapping sensors may be able to be placed in compartments to map the location of all machinery systems. After damage, these sensors may produce new map images of the compartment in lieu of human investigators.

3.4 Voice Communications

The view of a super computer in a pocket is supported by John Peterson and his projection that this power will support voice control of systems, as well as real time inter-personal communications language translation by the year 2000[xiv].

3.5 Personnel Locating and Monitoring

For years navies have spent millions of dollars on developing equipment health monitoring systems. The current emphasis is to augment time based maintenance with condition based maintenance. On a ship the people are more important than equipment. Up until to now, techniques to locate and monitor personnel in the civil and aerospace industry for security and productivity reasons have not been adopted by navies. Complete personnel locating and monitoring technologies are available and are the next biggest productivity step navies will take, especially as manpower is reduced. Each remaining person and their

associated skills becomes even more vital. Personnel locations and condition, both pre- and post- combat action or damage, will be vital to the performance of future ship systems.

3.6 Virtual Reality

All of the foregoing suggests that a "real" form of virtual reality will be achievable early in the 21st century. Cathode ray tube technology will give way to advanced combat rugged flat panel liquid crystal displays[xv] augmented with holographic 2D - 3D display systems[xvi]. As reported in July 1996, the advent of virtual people doing work is near. Norm Badler, director of the Center for Human Modeling and Simulation at the University of Pennsylvania, said virtual humans soon will work in a full spectrum of jobs. "If people do it, then virtual humans can do it. Any applications where humans need to work in real-time with games, military exercises, etc., all are possible."[xvii] It is not enough for virtual humans to look and move like a human; they must also be provided intelligence and personality. A computer program called Julia is being developed to add this dimension to the virtual humans. These technologies, properly applied, may have great impact on the design of new ships relative to the environment factors discussed previously and in view of the anticipated naval threats. Will we be able to advance from the virtual office of 1997 to the virtual command center of a naval ship or naval task force? Is true remote control possible?

3.7 Laser Weapons

After years on the drawing boards it appears that the era of laser weapons is emerging. Ship self defense laser weapons are being tested that cost in the range of $20M[xviii]. Laser weapons will provide the instant response needed, but will require high energy bursts. The energy for the lasers may be shared with the ships propulsion systems, hence the need to develop naval versions of electric drive propulsion.

3.8 Systems for Individual Sailors

New technology for individual soldiers and sailors is also advancing. A panel of scientists at Battelle made the following predictions as reported in the ADPA National Defense Magazine[xix].

- **Miniature electronics: Personnel in the future will have wearable integrated communications, locating, computing, and video devices**
- **Portable power: Portable power sources will increase in density**
- **Embedded training: Soldiers will be able to use their wearable computers to join in training up to the theater level.**
- **Precise treatment systems: Micro-scale medicine treatment will be developed to the cell / DNA levels. These treatments will help prevent / cure chemical / biological threats.**

- **Super Materials: The use of nanotechnology and similar technologies will provide stronger, lighter materials (uniforms / protective gear)**
- **Integrated Control Systems: Integrated control systems applied to manufacturing will reduce the cost of customized military component manufacture.**
- **Digital High Definition TV: HDTV, flat panel, will dramatically improve C4I and training.**
- **Hybrid Fuel: Future vehicles will be able to operate using various fuels (including hydrogen power)**
- **Genetic mapping: Genetic mapping may be used to build immunity to diseases and provide cures and may help when rendering humanitarian relief.**
- **Anti-aging services: Clearer understanding of stress and other aging factors may provide means to reduce the stress related impact on soldiers.**

3.9 Additional Technology Trends and Driving Forces

Space in this paper does not allow full description of all of the potential miracle technologies that may come into play during the life of our new ship. So listed below are some additional technologies that are forecast by John Peterson to come in play[xx].

- **Speed: Speed becomes the measure of value**
- **Global connectivity and accessibility: Everything is being connected to everything else.**
- **Power migrating toward individuals: Individual people will increasingly be able to access, analyze, and manipulate information (the source of wealth and power)**
- **Systems thinking: All things of importance will be increasingly viewed as systems.**
- **Organic models: Large systems will be increasingly seem to mirror and behave like organic systems**
- **Increasing complexity: Manufacturing systems will become increasingly complex including nanotechnology structures[xxi]**
- **Increased vulnerability: More complex systems will be increasingly vulnerable to instability.**
- **Information criminals: Criminal activity will increase significantly.**
- **Isolated perspective: Most of the world's population will not participate in the revolutions we discuss in this paper**

3.10 Technology Summary

The advances in technology in all areas will provide a war fighting environment in the future that we can only image today. When we look back to the world of 1945 our fleet admirals could not have imagined the SPY-1 radar based C4I systems with the potential of SM2 and Tomahawk cooperative engagement capabilities (CEC) over the horizon as we have seen with the Mountain Top trials by the US Navy[xxii]. And now it's our turn to wonder. What

new threats and technological responses will our ship and its crew have to face? Will there even be crews on some of the ships?

Section 4 will provide an overview of the threats and technologies available for response. In Section 5 we will examine personnel manning and training issues and then put it all together with a possible platform control system for 2015 and beyond.

4 The Threat

The good news is that the technologies we have discussed will provide additional leverage to improve the ship systems in the future. The bad news is, increasingly the enemies of freedom will have access to the same or similar technology. We can only trust that our will power and budgets will remain greater than theirs.

There are probably two types of threats that we face over the life of our new ship. One is relative to things we can detect and track (missiles, torpedoes, mines, etc. and their respective delivery systems). The other, which probably will be more difficult to counter, will be the unseen (chemical, biological weapons, information warfare, and the seemingly unstructured, "chaotic" makeup of enemy forces). As General Krulac put it, it will be increasingly difficult for organized and structured free world forces to deal with rogue dictators and terrorists[xxiii] whether they are acting independent of, or through, rogue governments like Iraq. Terrorists and insurgents seldom provide identifiable targets such as columns of armor. In the future they will more and more mask their actions within the civilian / commercial activities (commercial ships that can collect intelligence and lay remote controlled mines).

Another way to describe the threat is in terms of the missions future navies will perform. Likely missions might include:

- **Resource / Maritime Area patrols**
- **Anti-smuggling**
- **Immigration Control**
- **Home Waters Combat Operations (ASW, AAW, AsuW, AMW, etc.)**
- **Allied Naval Operations (ASW AAW, AsuW, AMW, etc.)**

However we look at the threat, the elements that we can depend on seeing will be surprise and speed (short reaction time). As stated at the beginning of the paper time is and will increasingly be the challenge. Hyper-velocity weapon systems combined with the surprise opportunities, especially in the littoral environment (islands, shallow water, etc.). This will require that the ship systems be able to react instantly, under all conditions to threats from any quarter. Figure 3 is a chart of response times versus speed and target detection range. Clearly, the prime measure of all future ship design will be system performance speed. System response time will be the MOE until enemy forces are capable of laser based weapons. At this point it will be imperative to eliminate the delivery vehicle before weapon release. After a laser weapon is fired, only active / passive countermeasures and shielding may be effective. But for

the next 15 years we may have to deal only with the easy threats - things we can detect, classify, track and shoot.

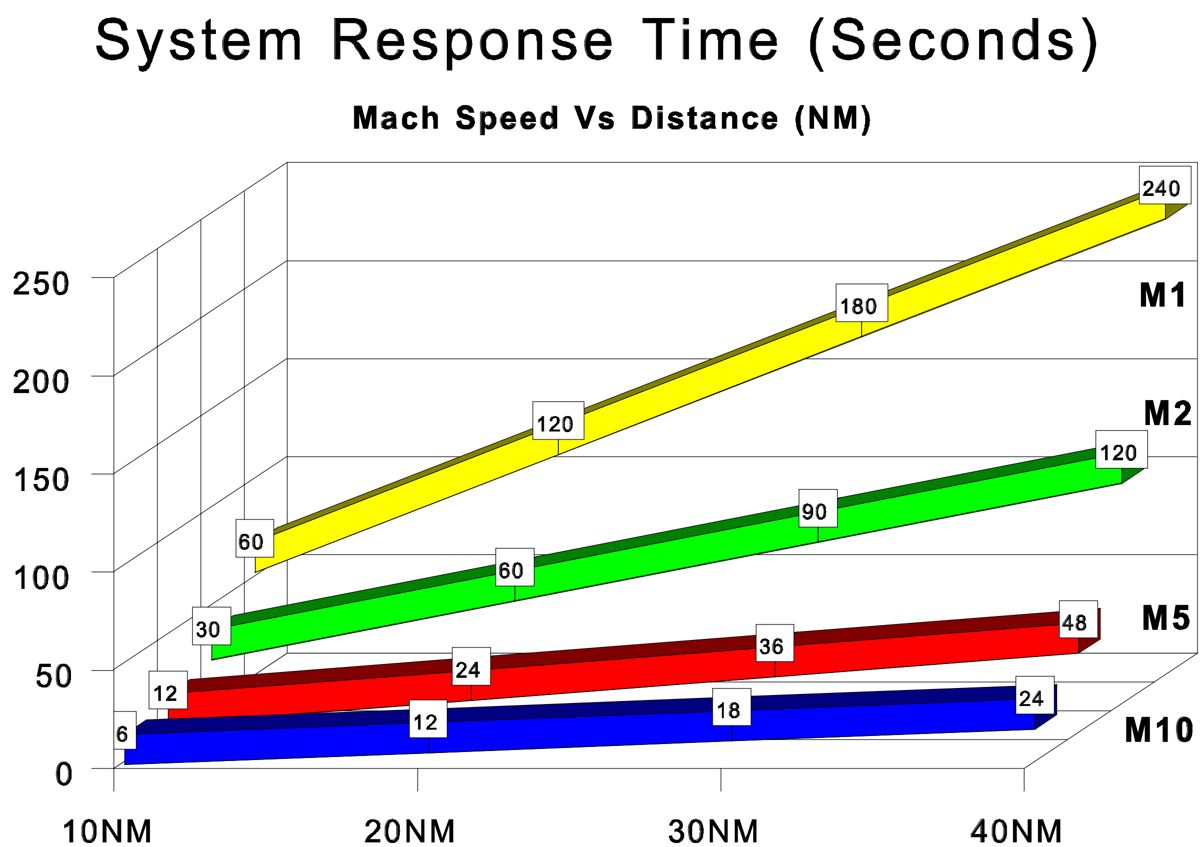
The design of our ship systems to meet these threats will be discussed in Section 5.

5 Future Platform Control Systems

5.1 General Design Considerations

Not every ship in the navy will be designed to the standards we recommend for our new ship here. But some will be, and they will operate in cooperation with ships of more traditional design. The design of our ship and its systems starts from the premise of a total system, not just the ship system, but ship in the context of the entire battle force (BF) and the BF supporting structure system. The ship will be a node: an active computer-based weapon system in the system. Ultimately, the new ship will have to be inherently capable of performing the ship's BF mission autonomously, with or without the crew.

We anticipate that, overtime, new ships will become viewed as they actually are, as machines of warfare and they will have a diminished role as an extension of national



sovereignty. A harsh statement, perhaps, and one that those of us who have had command at sea would not be happy to welcome. But the bottom line is that deterrence and battle mission performance is all that counts. Having personnel on board to show the flag and perform other duties, as we will see, is not only too expensive, but the people will be a determent to war fighting. Humans are not fast enough or strong enough for modern warfare. Our aviator friends have long held a similar view. If a $1 Billion B-2 bomber is lost, it is unfortunate. If the crew survives they are given another plane to fly. If a $1Billion ship is lost, it is the subject of the most severe consequences because a ship carries so many crew members and because the ship carries the flag. Yes, I would miss the romance of the old traditions too!

When ships are viewed in the same context as an M1A1 main battle tank costs may go down and performance up. There is only one class of ships in the world today that fits this description.

But in the 21st century manpower for defense will be in short supply. Manpower, if available, will be costly. Not only the direct cost, but the life cycle cost to design and sustain a ship that has a significant crew. Beyond this, there is the fact that humans are great thinkers, strategists and tacticians, but very poor physical war fighters against modern warfare technology. Humans are not sufficiently fast and strong, and they need fresh air and water to survive: a complete refresh of air every 15 to 30 seconds and about 100 gallons of fresh water every day. Humans are relatively weak compared to the massive steel structures that make up a ship and the weapons shot at them. Humans will not be able to react manually to future threats. Humans are a liability in severe damage control situations. Many have to rescued and attended to by large number of others. If any humans are lost in battle, the political consequences may be dire. The mission may be terminated.

5.2 Platform Control: 2015 and Beyond.

The future platform control system will incorporate the technologies discussed above within the environmental and threat envelopes as we see them now and as they evolve. This section of the paper will bring together these factors to define the control system objectives. We will define the future control system in terms of:

- **Performance**
- **The Battle Force System**
- **Damage Control**
- **Human Factors**

5.2.1 Performance.

5.2.1.1 Requirement: Speed is the critical factor. By 2015 our combatant ships will have adopted the speed performance of today's catamaran / SWATH fast ferries of 40 knots plus. Some may approach burst speeds of 100 knots. The weapons, fired from ships or shore, may be

hyper velocity. Laser weapons will require high energy thus the use of electric drive propulsion. For Mach 5 targets detected by a ship at 30 nm, the ship has 36 seconds to react.

5.2.1.2 Defined System: The platform control system will have to execute the following functions between target detection and the calculated time of impact:

Execute an engagement decision aid against the specific threat:

- **Best response weapon systems / active-passive countermeasures / placement**
- **Relative wind required for countermeasures**
- **Best relative attack angle to minimize radar cross section**
- **Best relative attack angle to minimize heat signature**
- **Best side (frame number) of the ship considering past damage / ammunition available to point defense systems**
- **Best relative attack angle to avoid vital spaces / personnel concentrations**
- **Full power to propulsion systems (assume combat systems charged)**
- **Full power generation on line**
- **Load shed of non-vital systems**
- **Damage control systems to full readiness: split vital systems into zones.**
- **Maneuver requirements: required turn versus rate of turn available**
- **Avoidance of shoal water and other vessels**

5.2.2 Battle Force System.

5.2.2.1 Requirement. By 2015 there will be no distinction between platform systems and combat systems on a ship. Further, the ship system will be a node of the battle force system. A command and control system based on ubiquitous computing will provide connectivity between individual personnel to ship systems to battle force command to battle force systems.

5.2.2.2 Defined System. In 1996 the apparent trend in naval platform control systems is to achieve higher levels of integration across both platform and combat systems. The newest ships are being designed with a ship wide area network (SWAN) that interfaces concurrently to both platform and combat systems processors and data bases. In the U.S., the Defense Advanced Research Projects Agency (DARPA) is currently providing R&D funding to developed faster SWAN networks, and operator associate AI-based decision aids that cut across both platform and combat systems. By 2015 the platform control system, subject of this conference, and the ships combat system will be completely integrated at the ship level and within the battle force command and control system.

The architecture will be based on ubiquitous computing. Personnel and ship systems will be computer enhanced. Because we cannot foresee all of the future requirements, what we must do is put into place an architecture that will allow the personnel and ship systems to be "connected" at future dates as new technologies emerge. One way to do this is to insure as a

minimum that a bundle of fiber optic cables is passed through virtually every compartment in the ships that we build. In future years, individual fibers or multiplex channels within a fiber can be assigned as required from anywhere to anywhere. If technology for RF wireless connectivity can be shown to be effective within a ship, then these appropriate antennas must be installed for future use.

Whether the architecture we install is fiber optic or RF, it must be able to support our requirements for 40 years.

5.2.3 Damage Control

5.2.3.1 Requirement. As in 1996, we project that in 2015 and beyond damage control will continue to be the major driver for ship design and manning. We will assume that the other major driver, maintenance, will have been solved through better equipment design, redundancies and modified policies and procedures. Damage control in an era of reduced crew size is a technical paper on its own merit. The requirement is to improve damage control systems and procedures in order to remove damage control as a manpower driver.

5.2.3.2 Defined Systems. Improving damage control in the future will be an iterative engineering cycle.

First, the ship must be designed in a wholly different way. Instead of designing ships with habitable space from stem to stern as is done today, ships must be designed with the maximum number of compartments to be inert. These compartments would be buffers around vital spaces, totally non-flammable, filled with inert gas / inert material to absorb damage / snuff combustion. Double or triple hulls must be used, with armor as required, including active armor on certain topside areas as used by battle tanks. SWATH and Surface Affect hulls may be used more widely to reduce the effects of underwater explosions and improve hull compartmentation. Remaining crew occupied spaces must be protected.

Second, as these new designs move forward the crew and their massive support systems (space for berthing, food, water production, air cleaning/distribution) can be scaled back providing more opportunities for step 1.

Third, damage control technology needs to be improved in order to further reduce the demand for people, leading back to step 1. New technologies for active damage control must be employed including automated fire suppression and dewatering in vital spaces, automated compartment isolation on demand (automated kill cards), use of advanced sensors (discussed previously) for post damage imaging, electronic damage plots, damage forecast based models of progressive flooding / fire spread, automated / remote control of water screens, etc.

Fourth, ships with fewer people will be viewed as war fighting machines and less as extensions of sovereign soil. This leads to two possibilities for damage control. First, the new ships we design may be operated during certain portions of their on station mission totally unmanned. Ships like arsenal ship may be put into remote control to maintain a specified range and bearing from the control ship which then use the arsenal ship as an extension of its

own missile magazine. Second, if the crew remains aboard, and if the damage decision aids show that the ship can be saved then the crew will continue damage control efforts augmented by help from the control ship(s) who will be able to read the machinery / damage control displays on their respective ships in real time. The control ships will send personnel and equipment as required. If the damage decision aid projects that the ship cannot be saved, then the crew, in its "floating" control center capsule will jettison themselves out the stern / side of the ship to be picked up by a naval rescue team when appropriate. Billion dollar B-2 bombers use this strategy.

5.2.4 Human Factors.

5.2.4.1 Requirement. Human factors are the most important element in the design of the control system for our new ship, and have been saved for last. This is where it all comes together. As stated earlier, humans are great strategists and tacticians, but no match for Mach 5 weapons. For example, the large number of personnel we have on ships today is driven by damage control requirements that are driven by the fact that there are a large number of personnel on the ship in the first place. It's a cycle. We must design our new ship with this principle in mind.

Comment:* *Another element in our definition of our requirements is one that we cannot deal with very effectively, anymore than did the generations ahead of us. Past success is our worst enemy[xxiv]. This is related to the fact that as we apply new technologies, we generally apply them to the work we do now, as we do it now. It generally takes us years to realize that the new technologies actually provide new ways of doing things or can provide the means to eliminate doing things. We all remember the advent of automated data processing (ADP). In the then current grey flannel suite corporate culture, ADP just allowed us to increase our vertically integrated organizations, faster and bigger. We were not all that pleased with the huge bureaucracies that resulted in corporate life or in government. We will have to think very hard, try new technologies and learn to fail, fast, even as we run right into our own cultural walls, as we try to introduce fundamental change.

5.2.4.2 Defined System. Since manpower will be increasingly scarce as well as expensive to acquire, train and support, we must try reduce this cost. At the same time, the ship must be able to perform its designed missions. The defined system will therefore use technology to support the humans by doing all of the routine functions, and most battle / emergency function, leaving to the humans the things they do best: strategic and tactical thinking, and complex decision making. As of May 1996, the best computer and software program system money could buy was defeated repeatedly by a human in a chess match[xxv]. Human judgment will be essential whether operating "on" our new ship or operating our ship by remote control on certain missions.

The human factors must take into account that the ship, each system in the ship, and each individual person in the ship is an integral part of the overall battle force system. The battle force system will be capable of knowing the instantaneous status of all personnel, every significant item of equipment, every system, every sensor, and every weapon. The ships and their systems will interact as appropriate according to a defined doctrine.

The ship systems, both platform and combat systems, will be employed (orchestrated) to perform the mission in the most efficient manner. Intelligence, missions and targets will be passed through out the system. The ship with the best shot at a target will be employed to engage that target even when the target is "seen" second hand. For rapid reaction threats, the ship will automatically maneuver for the best firepower angle unless overridden by human command.

Each person in the crew will be outfitted with a wearable "compucater" (computer - communicator) and life support system. The power of the compucator, who it can speak to and when will be controlled by voice matched access control system, both plain and secure. Based on doctrine and the mission event in progress, some or all crew members will be monitored as to location and health. Locating transponders will be located throughout the ship. Individual health will be monitored using light weight bands of sensors worn by the crew members (similar to those worn aboard space craft today). During a normal watch, only watch standers would be tracked and monitored. At General Quarters, and after damage or during an emergency, all crew members would be tracked and monitored. Compucators will be two-way devices allowing orders to the crew members. Their assigned activities will be tracked such as when assigned to a firefighting party or given an OBA (tasks now done manually). The location and health of each will be monitored. The compucators will be augmented by a screen / eyepiece device that will permit the crew member to perform the following functions:

- **Conduct maintenance using an electronic tech. manual**
- **Perform training at all levels, individual, to ship wide, to force wide.**
- **Perform mission duties from the crew member's current location as if the member was at the assigned station using voice commands and/or virtually reality type body motions.**
- **Perform command and control duties, both combat systems and platform systems as if the crew member was actually at the assigned general quarters station with his console (man-machine interface) in front of him. If it is normal to see other crew members to his right / left, the other members will be "seen" by turning his head right / left.**
- **Interact with the other members of the watch team as if they were collocated. The actual "face" features / expressions of the other crew members will be superimposed on the virtual human heads.**
- **All MMI features for both platform and combat systems will sufficiently common that cross training is readily accomplished.**
- **Automation and remote control of systems will be in accordance with doctrine, augmented by real-time system/equipment health monitoring.**

5.2.4.3 Composite Command Centers (C3) In addition to the individual wearable compucator systems the ship may have two or more composite command centers. Each of these centers will have actual, full, multi-function seats (formerly-consoles, common to both platform and combat systems). These new battle seats will support extended watch routines with both local vision screens and a view of a larger screen or two in the compartment that supports 2D, 3D and holographic imaging. One or all of the C3 units will be usable in any combination, to either congregate the crew, or disperse the crew, depending on the circumstances.

Each C3 unit will use a combination of MMI / visual displays, including holographic 3D situation displays. Complete ship control will be provided in each center (as well as from authorized compucators) including course and speed. The current versions of electronic charts will be provided with radar / sonar / thermal / low light / ESM / Intelligence (all sensors) overlay, and autopilot. Voice control will be possible.

Each C3 will be sufficiently large to contain the entire ships crew and provide for full life support for up to 48 hours. Each C3 will be hermetically sealed to filter against NBC agents. Each C3 will be capable of being jettisoned with the crew embarked should loss of the ship be eminent. The C3 unit will float in the ocean with zero freeboard, and be equipped with a periscope / locating / communications antennas for recovery.

5.2.4.4 Situational Awareness. A key design consideration of the new compucators and C3 units will be human factors design for situational awareness. As reported in Aerospace[xxvi] the manner in which automation is implemented makes a marked difference in the success of the application. Recent airline accidents involving highly automated cockpits have that automation may be outpacing training programs and failing to keep pilots sufficiently in the loop. This article is a very good case study of two different approaches. The one where the pilot must stay in the loop is more effective than the other. Another approach to manage the flood of data / information presented to personnel decision makers is better aggregation and visual presentation on the CRT displays. The new technology may also incorporate the use of artificial intelligence to augment the display of information to add the dimension of "intentions": is the contact, based on its profile, on an intelligence mission or attack mission?[xxvii] . The methods to use these new human factors technologies are discussed in the Naval Engineers Journal, July 1996.

5.2.4.5 Ubiquitous Communications. Much has been said of the ability of the new computers and bandwidth to provide ubiquitous computing. In parallel, there will be ubiquitous communications, based on priorities, command structure and doctrine. The commanding officer of a ship will be able to initiate two-way communications within his command or to any unit outside the commander's command from any position in the ship, any time, by simply speaking the address and the message.

5.2.4.6 Impact of High Automation on Personnel.

In previous discussions of highly automated ships the question has been asked, but what about the impact on personnel? What qualifications do they require? What training and education must they have to perform in this environment?

Obviously, as the crews get smaller, the operational value (contribution) of each individual grows in proportion. But the key is remembering why people are necessary in a combat situation. People are there to do the things that computer controlled machines cannot do. Period. That contribution is human judgment (insight and reflection).[xxviii] Strategy, tactics, intuition, and anticipation: these are traits that will be necessary.

Yes, humans will be there to oversee the ship and combat/machinery systems and combat and machinery engineering skills will be required aboard to evaluate the situation using the traits noted above. But the complexity of future systems will leave very little to be done physically in the way of repair. Total quality and complete redundancy of systems must be provided.

All personnel will have to have an excellent comprehension of computer AI/ES-based systems, including the make-up and logic in the algorithms. The humans must be able to sense when the computer is out of its league. Critical skills however, will be based on a sound foundation of history and the humanities in addition to the technical skills noted. Expertise in strategy and tactics requires a keen sense of history and driving forces augmented by current events. This relates back to the comments of General Krulac on the challenge of future chaos situations. How else do we make sense of seeming chaos except to understand the underlying historical-socio-economic drivers? Chaos seems to denote a random occurrence, but successful enemy forces must have an objective and a "cultural" bias on how to achieve it. Allied forces will need to sense and anticipate these situations.

While all of this may seem a long way from the evolution of machinery control systems to integrated ship systems, it is just extension down the same line. Will it happen? If not soon, when? History seems to support the observation that anything imagined, subsequently found necessary, materializes. In 1955, I wrote a high school term paper entitled, "Destination Moon," based on the inspiration of famous author, Arthur Clarke. It all happened by 1969, in almost exactly manner described. The court is still out, but this is what we think.

5 Conclusions

This paper has assumed as a given the distributed sensors and computers necessary to automate all future platform machinery systems and to integrate the machinery systems with the combat systems. This is considered the easy part. It's pure engineering with a few major cultural hurdles. The more difficult part is deciding what to do with this technology and the related implication on the human and human factors in the context of future warfare.

It's not just a ship anymore! It's a node in the free world defense system. Did we define the design elements of our new ship (node) and its control system right? Close, maybe? Our guess about the spin of future events cannot be any better than the collective intelligence

and imagination of this conference. However, if we have created some new thought patterns and caused some new questions to be asked, then we have been successful.

We will have to think very hard as we try new technologies. We need to learn how to try, including the acceptance of failure. We must learn to fail fast, even as we run right into our own cultural walls, as we introduce fundamental change. We tend to learn more from our mistakes than from what we do right.

Let's go to the future!

The conclusion will not be available for another 40 years!

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